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ESTABLISHMENT OF A SUPER SMALL-SCALE COOKOFF BOMB (SSCB) TEST FACILITY AT MRL

R.P. Parker

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ABSTRACT

A Super Small-scale Cookoff Bomb (SSCB) test facility has been established at MRL to provide data on the cookoff behaviour of energetic materials. The test uses an explosive sample of about 20 g, and the heating rate can be varied.

This report describes the test equipment, and reports SSCB test results for several melt-cast explosives and a series of RDX/TATB/Viton compositions.

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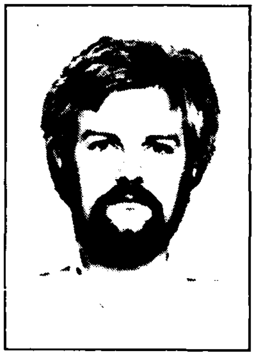

AUTHOR

Robert Parker graduated Dip App Chem from Ballarat School of Mines and Industries in 1968, and joined MRL in that year. He has worked exclusively on explosive materials; his present major areas of interest are cookoff of explosives and PBX formulations.

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ESTABLISHMENT OF A SUPER SMALL-SCALE COOKOFF BOMB (SSCB) TEST FACILITY AT MRL

1. INTRODUCTION

An area of increasing concern throughout the military explosives community is the behaviour of energetic materials (explosives, propellants, initiators and pyrotechnic compositions) when subjected to external heating, commonly referred to as cookoff behaviour. Typical of the requirements for such behaviour in complete munitions systems are those of the US Navy [1], where munitions systems are required to pass cookoff tests at both fast and slow heating rates. The response of the system (e.g. detonation, explosion, burning) and the time to reaction must be determined.

Fast cookoff tests on munitions systems are designed primarily to assess the munition's reaction on exposure to a fuel-fire, and are generally performed in a close to real-life fashion [2,3]. Slow cookoff tests [1] are designed to assess the munition's reaction when exposed to lower heat fluxes, eg. when stored adjacent to a compartment where a prolonged fire occurs. Such large-scale tests, while necessary for qualification of a complete munition system, are obviously inappropriate during development programs; in particular, when new energetic materials or formulations are being developed, tests of a significantly smaller scale are needed to assess the material's response to thermal stimuli.

There are a number of tests which can be applied to small amounts of explosives to yield information on thermal stability, self-heating, and cookoff behaviour under various conditions.

The thermal decomposition of materials can be conveniently studied on small laboratory-scale samples using a variety of thermochemical techniques, such as Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), Thermogravimetric Analysis (TG), Accelerating Rate Calorimetry (ARC), and Henkin tests. These techniques can yield information on the kinetic parameters, e.g. activation energy, pre-exponential factor, heat of reaction. Such information can then be used, in combination with other material properties, to predict the response of the material to particular thermal stimuli [4-12]. Thermal explosion theory [13-19] can be used to predict thermal initiation of explosives, and many studies have compared predicted and real-life critical temperatures and times-to-explosion [20-28].

While the information gained from such tests and predictive studies is invaluable, there is nevertheless a major drawback to their use in that no indication of the severity of the reaction is obtained. Accordingly, a number of small-scale tests have been developed to assess the response of confined explosives to thermal initiation [4,27,29-36]. In some of these tests, confined samples are ignited directly via a hot-wire/propellant ignition system [29-32] and the response ('explosiveness') of the explosive is assessed. In other tests, small-scale fuel-fires are used to heat the confined samples [27,32-34]; these tests yield additional data on temperature-time history prior to initiation, but are inconvenient to conduct and may give poor reproducibility since heating rates etc. are difficult to control. Tests using confined samples heated via a controlled external heat source (electric band heaters) [4,32,35,36] afford the possibility of obtaining the same data as in the previous tests, but with improved reliability and predictive capability. One of these, the Small-scale Cookoff Bomb (SCB) test [4,36], has been adopted by the UN as a suitable test for classifying energetic materials in regard to their thermal response [37].

It was decided to establish the Super Small-scale Cookoff Bomb (SSCB) test [35] at MRL as the first stage in a program to assess the cookoff behaviour of existing and new explosive formulations, particularly PBXs (polymer bonded explosives) which are formulated to minimize cookoff response. The SSCB test should also be particularly appropriate for examining booster formulations, since the charge size/geometry is similar to the boosters used in many in-Service fuzes.

2. EXPERIMENTAL

The design of the SSCB test assembly was taken directly from that used at Naval Weapons Centre (NWC), China Lake, CA. [35]. Using an existing test geometry will allow direct comparison of published results from different laboratories. The NWC SSCB test is also used at other US establishments, e.g. Naval Surface Warfare Center (NSWC), White Oak, MD., and some European laboratories [38], and may become a standard test, as has the SCB test [37].

The SSCB test uses a sample of about 20 g of energetic material, in a cylindrical geometry with a diameter of 15.9 mm and a length of 63.6 mm. Heating is effected by means of electric band heaters, and the heating rate experienced by the sample can be varied by varying the voltage applied to the heaters. A fast heating rate, similar to that experienced by the filling of a munition in a fuel-fire, and a slow heating rate, such as experienced by thermally-protected munitions or in situations where heat conduction occurs through the metal parts of a munition to an explosive component deep inside the munition, can be obtained with this test apparatus [35].

2.1 Description of SSCB Test Vehicle

The SSCB test vehicle is shown diagrammatically in Figure 1, and photographs of the hardware before and after assembly are shown in Figures 2 and 3, respectively. The test vehicle consists of an outer steel cylinder which is spot-welded to a 9.5 mm thick steel baseplate. Two band heaters, each rated at 250 W/240 V, are clamped around this cylinder with hose-clamps, and are connected to a variable voltage supply (Variac) to provide heating at the desired rate. The Variac is set to supply 240 V or 120 V for the fast or slow heating rates, respectively. An aluminium liner cylinder (sometimes with a sealed base - see later discussion) with a slot for a thermocouple for monitoring the temperature-time history during the test is placed inside the outer cylinder. This liner serves as a heat sink to even out the heating delivered to the sample from the heaters [35], which are not completely symmetrical. The explosive sample, either cast directly or pressed as close-fitting pellets, is placed in two inner steel cylinders which are inserted into the aluminium sleeve. A thin standoff washer is placed below the inner cylinders and explosive and provides an air-gap between the explosive and the baseplate (or, when a sealed-base liner is used, between the liner base and the baseplate). A steel top plate, also 9.5 mm thick, closes the top of the test assembly, and is secured to the baseplate with four bolts. The top plate incorporates a hole for the thermocouple which is located in the slot in the aluminium liner, and also has a central hole which is closed with a steel plug as the last step in the assembly of the apparatus for each test.

2.2 Explosive Compositions

The explosive compositions selected for initial testing in the SSCB were several TNT-based melt-cast compositions, including Composition B, the most widely used shell filling, pressed tetryl, the most common booster explosive found in explosive trains of in-service munitions, and a series of pressed RDX/TATB/Viton A compositions, selected to provide comparative data between the SSCB test being established here and that originated and used by NWC [35]. Details of the explosive compositions used are given in Table 1.

The TNT-based explosives were cast directly into the inner cylinders, and high-quality charges with densities as listed in Table 1 were produced.

The RDX/TATB/Viton A compositions were prepared using a solvent coating process (see Appendix A), to produce moulding powders comparable to those supplied by NSWC for testing by NWC [35]. The complete range of compositions tested by NWC was not duplicated; the compositions chosen for testing were selected to cover the range of cookoff responses [35]. Additionally, a sample of US-produced PBXW-7 Type II (NSWC ID #3409) corresponding to the 35/60/5 RDX/TATB/Viton A composition, was tested to determine whether we observed any discrepancies in cookoff response due to differences in coating efficiencies in our preparation of the moulding powders. It has been reported that the coating efficiency can have a pronounced effect on the type of cookoff reaction obtained [39].

The tetryl and RDX/TATB/VitonA compositions were pressed into pellets of a suitable size to fit snugly into the inner cylinders, using an Instron Mechanical Tester operated as a press; all the materials were pressed to approximately 90% TMD (Theoretical Maximum Density).

2.3 Temperature Calibration

The temperature recorded during an SSCB test is that sensed by the thermocouple in the slot in the aluminium liner, located between the heaters (on the outside of the test assembly) and the explosive (within the inner cylinders). The temperature reached by the outer surface of the explosive sample during the test is obtained from a calibration chart produced by heating an inert-filled SSCB which has a second thermocouple welded to the inner surface of the inner cylinder; the two temperature/time curves obtained allow the temperature reached by the explosive to be estimated from the recorded temperature in the liner slot. Heating runs are conducted at both fast and slow heating rates to produce calibration charts for both conditions.

The temperatures are measured using Type K thermocouples, connected to dedicated thermocouple amplifiers, built using AD595AQ thermocouple amplifier integrated circuits, which provide an output of 10 mV/°C. The output from the thermocouple amplifiers is recorded using a strip-chart recorder. On some occasions during the tests reported here, these thermocouple amplifiers were not functioning; temperature measurements were then made directly from the thermocouple output via an ice-point reference.

2.4 Conduct of Tests

The SSCB tests are conducted in a firing chamber, with the power supply for the heaters and the thermocouple amplifier/chart recorder located in remote control and instrumentation rooms, isolated with safety interlocks. The SSCB is suspended vertically, with the baseplate down, in the centre of a large steel cylinder approximately 30 cm diameter x 45 cm high, and covered with a steel plate, to assist in fragment recovery after the event. Power is applied to the heaters from the control room, and the time to the event is measured with a timer-watch. The thermocouple temperature is also monitored in the control room, and provides an indication that the test is proceeding normally, e.g. heater malfunctions can be detected.

After the event, the SSCB fragments are recovered from the chamber, together with any unconsumed explosive, and examined. The bulging of the end plates is measured with a depth micrometer (readings are taken to the nearest millimeter), and any hole in the baseplate is measured. The damage to the cylinders is noted, and a photograph to record the condition of the fragments is taken. The thermocouple temperature is obtained from the chart record, and the temperature experienced at the surface of the explosive is derived from the appropriate calibration curve.

3. RESULTS

3.1 Heating Rates and Temperature Calibration

The actual heating rates and temperature calibration curves obtained for the nominal fast and slow heating rates, with heater voltages of 240 V and 120 V respectively, are shown in Figures 4 and 5. The heaters used with the SSCB are rated at 250 W/240 V, and are therefore not identical to those used by NWC, which are rated at 125 W/120 V [35]. Nevertheless, the heating rates obtained here are very similar to those reported by NWC - at the fast heating rate a temperature of 300°C is reached in about 5 minutes, and at the slow heating rate a temperature of 230°C is reached in about 30 minutes. The differences between the measured temperature (in the slot in the aluminium liner) and the temperature experienced by the surface of the explosive (obtained from the calibration curves) are less than those reported by NWC [35]. The temperatures at which reaction occurs reported for the various explosives will be inaccurate for several reasons - small variations in heaters, applied voltages and thermal properties such as thermal conductivity and specific heat between different tests, thermocouple amplifier accuracy, and chart recorder accuracy/readability - but it is estimated that the temperatures will be in error by not more than 5°C. Results of replicate tests on a given explosive composition (e.g. RDX/TATB/Viton 35/60/5 and PBXW-7 Type II - see Table 3) indicate that this is a realistic estimate of test reproducibility, although the sample variability may be greater than this (see Discussion).

It should also be noted that the reported explosive surface temperatures are obtained from calibration runs using an inert material, and no allowance has therefore been made for any temperature increase arising from self-heating of the explosive prior to reaction. At the fast heating rate, the self-heating contribution to the explosive surface temperature is expected to be small, but it may be appreciable (perhaps several °C error arising from its neglect) at the slow heating rate - see section 3.2.1 below.

The calibration curves are normally used only to obtain the explosive surface temperature corresponding to the observed thermocouple temperature, i.e. the absolute position on the time axis is ignored. In the results which follow, estimates of explosive surface temperature have been made for several tests where no temperature record was obtained, using the time-to-reaction to obtain the temperature directly from the calibration graph. In these cases, the temperature error may be higher than discussed above, since there is some run-to-run variation in the exact heating rate curves obtained. This is illustrated in Figure 6, where the individual thermocouple temperatures and times to reaction for all the fast heating rate tests are plotted, together with the thermocouple temperature-time curve from the fast heating rate calibration curves. This run-to-run variability means that a longer time-to-reaction does not necessarily imply a higher cook-off temperature.

3.2 Test Results

The results obtained for the meltable explosives (TNT-based melt-cast compositions and tetryl) and for the RDX/TATB/Viton compositions are summarized in Tables 2 and 3, respectively, and photographs showing the damage to the baseplates and the fragmentation resulting from the various types of reaction are presented as Figures 7 to 12 (see also Discussion). Descriptions of the individual test reactions observed are detailed below for all the materials examined.

3.2.1 TNT

At the fast heating rate, reaction occurred after 422 seconds. The measured temperature was 367°C, corresponding to an explosive surface temperature of 343°C. The baseplate was bulged 5 mm, and the top plate had the plug blown out and was bulged 6 mm. The outer cylinder was split and peeled open, but was still in one piece. The aluminium liner was split along the thermocouple slot. Both inner cylinders were intact, with no apparent damage or bulging. All the metal parts were covered with a black sooty residue. This reaction is classed as burning.

For the test at the slow heating rate, an aluminium liner with a thin (approx. 2 mm) base welded to it was used. This was an attempt to limit loss of molten material prior to reaction, a phenomenon previously observed with tetryl (see later results and discussion), and also reported by NWC [38]. Reaction occurred after 3156 seconds (52:36 minutes). The measured temperature was 296°C, corresponding to an explosive surface temperature of 295°C. A gradual increase in the rate of temperature rise was observed for several minutes before reaction, presumably due to a relatively slow exothermic decomposition of the TNT before the runaway thermal reaction. The SSCB was essentially intact after the test, but covered with a sooty deposit. After disassembly, it was found that the baseplate was bulged 4 mm, and the top plate had the plug blown out and was bulged 5 mm. The outer cylinder spot welds had broken from the baseplate, and the cylinder was slightly bulged at the top. The liner was split along the slot, and the base was detached. A pool of molten explosive residue was found on the floor below the SSCB, and 3.4 g of material was recovered and identified as TNT. This reaction is classed as mild burning.

3.2.2 Composition B

Two tests were conducted at the fast heating rate, and reactions occurred after 255 and 245 seconds. The measured temperatures were 277°C and 280°C, corresponding to explosive surface temperatures of 246°C and 248°C, respectively. For the first test, the SSCB was placed directly on the steel-lined concrete floor of the firing chamber. The baseplate was not holed but a very severe flat-bottomed bulge 11 mm deep and about 45 mm diameter was produced; it is considered certain that a hole would have been punched in an unsupported baseplate. The top plate had the plug blown out and was bulged 15 mm. A large number of small fragments were produced from the cylindrical portions of the SSCB, and none could be reliably identified as to their origin. This reaction is classed as a detonation. In the second test, the baseplate was not holed, but a bulge 10 mm deep was produced. The top plate had the plug blown out and was bulged 10 mm. The outer cylinder and the aluminium liner were fragmented into a number of pieces (17 and 13 found, respectively). One inner cylinder was intact but severely bulged, the other inner cylinder was split vertically into 4 pieces. This reaction is classed as a violent explosion.

At the slow heating rate, reaction occurred after 1520 seconds (25:20 minutes). The measured temperature was 214°C, corresponding to an explosive surface temperature of 212°C. A sharp temperature rise was observed on the chart recorder temperature trace just prior to reaction, presumably due to appreciable heat generation from reaction at a relatively slow rate (timescale of several seconds); the temperature reported above ignores this spike on the chart record. The baseplate had a small irregular-shaped hole, about 20 mm x 3 mm, with a small amount of scabbing from the rear surface. The top plate had the plug blown out and was bulged 11 mm. The outer cylinder and the aluminium liner were fragmented into a number of pieces (15 and 14 found, respectively). One inner cylinder was intact but bulged at one end, the other was split into three pieces. A small amount of explosive (1.2 g) was recovered from the chamber floor. This reaction is classed as a detonation, but it is considered likely that the deflagration-to-detonation transition which would follow a thermal initiation in this test was barely complete.

3.2.3 Pentolite

At the fast heating rate, reaction occurred after 238 seconds. The measured temperature was 265°C, corresponding to an explosive surface temperature of 234°C. The baseplate was bulged 9 mm, and the top plate had the plug blown out and was bulged 11 mm. The outer cylinder and the aluminium liner were fragmented into a number of pieces (18 and 7 found, respectively). One inner cylinder was intact but severely bulged, and the other inner cylinder was split into 3 pieces. This reaction is classed as an explosion.

At the slow heating rate, reaction occurred after 2432 seconds (40:32 minutes). The measured temperature was 254°C, corresponding to an explosive surface temperature of 252°C. The SSCB was intact after the test; no visible distortion of any components had occurred (although the bolts may have stretched slightly, as a 'wash' of soot was apparent on the underside of the top plate), and the plug in the top plate was not blown out. The explosive in this test was contained in a sealed base aluminium liner, but 11.1 g of solidified material was found on the floor below the SSCB; this was recovered and subsequently found to consist of 64% TNT and 36% PETN. When disassembled, the SSCB was found to contain a residue of fluffy soot; no explosive material was found inside the SSCB, however. This reaction is classed as mild burning.

3.2.4 Tetryl

Three tests were conducted at the fast heating rate, and reactions occurred after 239 and 240 seconds; no time was measured for the third test, since the wrong heating rate was inadvertently used for several minutes at the start of the run. The measured temperatures were 285°C, 268°C and 268°C, corresponding to explosive surface temperatures of 257°C, 238°C and 238°C respectively. In all cases, a hole was punched in the baseplate (hole sizes of 35 mm diameter, 12 mm x 20 mm, and 25 mm diameter respectively), all the plugs were blown out of the top plates, and the top plates were bulged 12 mm, 9 mm and 14 mm respectively. In all cases, a large number of fragments were produced from the cylindrical portions of the SSCBs, none of which could be reliably identified as to their origin, except for the second test where one inner cylinder was recovered considerably bulged and split open. These reactions are classed as detonations.

Three tests were conducted at the slow heating rate, and reactions occurred at 1123, 1180 and 1177 seconds (18:43, 19:40 and 19:37 minutes). The measured temperatures were 207°C,198°C and 199°C, corresponding to explosive surface temperatures of 205°C,196°C and 197°C respectively. In the first test, the baseplate was bulged 8 mm, and the plug was blown out of the top plate which was bulged 7 mm. A film of melted explosive was present on the top of the top plate, and more explosive (3.3 g) was recovered from the floor below the SSCB. The outer cylinder was split into 4 pieces, and the aluminium liner was split into 2 pieces. Both the inner cylinders were intact, with no apparent distortion. This reaction is classed as burning. In an attempt to prevent loss of molten sample prior to reaction in subsequent tests, the aluminium liners to be used at slow heating rates had their bases sealed with a thin welded aluminium plate, which is now the standard NWC test configuration [38]; the second test used this configuration. In the second test, the baseplate was bulged 8 mm, and the plug was blown out of the top plate which was bulged 8 mm. Again, a film of melted explosive was found on the top of the top plate, and more explosive (4.7 g) was recovered from the floor. A small amount of explosive was also found on the inner surface of the aluminium liner base. The outer cylinder was split into 6 pieces and the aluminium liner was split into 2 pieces and the base was detached. One inner cylinder was bulged at one end, and the other was bulged in the centre. This reaction is classed as a deflagration. The third test was observed with a high-speed video camera, operating at 2000 frames/second for the actual reaction and in real-time for the preceding time, in an attempt to determine when and where the recovered explosive originated. The event obtained was very similar to that in the second test. The baseplate was bulged 10 mm, and the top plate had the plug blown out and was bulged 9 mm. The outer cylinder was split into 6 pieces, and the aluminium liner into 3 pieces and the base was detached. One inner cylinder was bulged in the centre. This reaction is classed as a deflagration. The high-speed video did not provide any useful information at the time of the runaway reaction, but the real-time video prior to the event showed molten tetryl being exuded from the thermocouple entry hole for several minutes prior to reaction. Initially, a small pool of molten material gathered on the top plate, and then ran down the sides and fell to the floor; as the temperature increased, the exuding material started to spray as a thin stream to a height of several centimetres above the SSCB. After the test, 4.4 g of melted explosive was recovered from the chamber floor; subsequent examination showed it to be tetryl, identical (as evidenced by gas chromatographic analysis) with the original material.

3.2.5 RDX/Viton 95/5

At the fast heating rate, reaction occurred after 271 seconds. Due to a malfunction in the instrumentation no temperature record was obtained; an estimate of about 260°C for the explosive surface temperature was made from the time to reaction. A slightly ragged hole, about 25 mm x 30 mm, was punched in the baseplate; the top plate had the plug blown out and was severely bulged 16 mm and cracked. A large number of small fragments were produced from the cylindrical portions of the SSCB, none of which could be identified as to their origin. This reaction is classed as a detonation.

At the slow heating rate, reaction occurred after 1577 seconds (26:17 minutes). The measured temperature was 219°C, corresponding to an explosive surface temperature of 217°C. A 38 mm diameter hole was punched in the baseplate; the top plate had the plug blown out and was bulged 15 mm. A large number of small fragments were produced from the cylindrical portions of the SSCB. This reaction is also classed as a detonation.

3.2.6 RDX/TATB/Viton 70/25/5

At the fast heating rate, reaction occurred after 294 seconds. The measured temperature was 294°C, corresponding to an explosive surface temperature of 265°C. The baseplate was bulged 7 mm; the top plate had the plug blown out and was bulged 7 mm. The outer cylinder was split into 3 pieces, and the aluminium liner was split along the slot. The inner cylinders were intact; one showed no apparent distortion, while the other was bulged at one end. A small amount of explosive (< 1 g) was present on the underside of the top plate. This reaction is classed as a deflagration.

At the slow heating rate, reaction occurred after 1543 seconds (25:43 minutes). The measured temperature was 223°C, corresponding to an explosive surface temperature of 221°C. A 35 mm diameter hole was punched in the top plate, while the baseplate was bulged 10 mm. A large number of small fragments were produced from the cylindrical portions of the SSCB. This reaction is classed as a detonation.

3.2.7 RDX/TATB/Viton 35/60/5 and PBXW-7 Type II

The results for RDX/TATB/Viton 35/60/5 and PBXW-7 Type II are presented together, since both materials have the same composition, but were obtained from different sources.

Two tests with RDX/TATB/Viton 35/60/5 and one with PBXW-7 Type II were conducted at the fast heating rate, and reactions occurred after 302, 263 and 266 seconds. The measured temperatures were 290°C, 297°C and 293°C, corresponding to explosive surface temperatures of 262°C, 270°C and 265°C, respectively. In the first test with RDX/TATB/Viton 35/60/5 and the test with PBXW-7, the baseplates were both bulged 4 mm, and both top plates had the plugs blown out and were bulged 4 mm. The outer cylinders were partly split open from the top, but were each in one piece, and the aluminium liners were split along the slot. All the inner cylinders were intact, with no apparent distortion. Charred explosive residue was present on the underside of the top plate and on the inner cylinders, and lumps of explosive (totals recovered 10.8 g and 8.1 g respectively), some showing obvious charring, were scattered around the chamber. These reactions are classed as burning. In the second test with RDX/TATB/Viton 35/60/5, an irregular hole about 17 mm x 10 mm was punched in the baseplate; the top plate had the plug blown out and was bulged 9 mm. The cylindrical portions of the SSCB were broken into many large and small pieces, including several split and severely bulged parts of one of the inner cylinders. This reaction is classed as a detonation.

One test each on RDX/TATB/Viton 35/60/5 and PBXW-7 were conducted at the slow heating rate, and reactions occurred after 1462 and 1657 seconds (24:22 and 27:37 minutes) respectively. The measured temperatures were 212°C and 215°C, corresponding to explosive surface temperatures of 210°C and 213°C respectively. The baseplates were bulged 10 mm and 9 mm, and the top plates had the plugs blown out and were bulged 7 mm and 9 mm respectively. The outer cylinders were split into several pieces, as were the aluminium liners. All the inner cylinders were bulged, and one from the RDX/TATB/Viton 35/60/5 test was split into two parts. Traces of explosive residue (as a thin film) were present on the end plates and the inner cylinders. These reactions are classed as an explosion and a deflagration, respectively.

3.2.8 RDX/TATB/Viton 20/75/5

Three tests were conducted at the fast heating rate, and reactions occurred after 250, 248 and 277 seconds. In the first test no temperature record was obtained due to a malfunction in the instrumentation; an estimate of about 255°C for the explosive surface temperature was made from the time to reaction. In the second and third tests the measured temperatures were 283°C and 302°C, corresponding to explosive surface temperatures of 255°C and 274°C respectively. In the first test the baseplate was bulged 5 mm; the top plate still had the plug present and was bulged 5 mm. The outer cylinder was split into 2 sections, and the aluminium liner was split along the slot. The inner cylinders were intact, with no apparent distortion. A lump of explosive was stuck below the plug in the top plate, traces of explosive were present on the inner cylinders, and lumps of explosive (4.5 g recovered) were scattered on the floor. This reaction is classed as burning. In the second test the SSCB was recovered almost intact, although the bolts had stretched and the baseplate and top plate were bulged 2 mm and 5 mm respectively. After disassembling, it was found that the outer cylinder had split open for about 15 mm from the top, and the aluminium liner was split along the slot. The inner cylinders were intact with no apparent damage. The SSCB contained about 3 g of charred residue, but only traces of unreacted explosive were observed. This reaction is classed as mild burning. The third test was observed with high-speed video (2000 frames/second). The reaction which occurred was similar to those in the first two tests; the baseplate was bulged 5 mm, and the top plate was bulged 6 mm but still had the plug in place. The outer cylinder was split about 15 mm from the top, and bulged in the centre; the aluminium liner was split along the slot. The inner cylinders were intact with no apparent damage. A lump of explosive was stuck below the plug in the top plate, traces of explosive were present on all parts, and powdered explosive and several lumps of explosive, some with charring on some surfaces, were scattered on the floor (6.3 g recovered). This reaction is classed as burning. The high-speed video showed the burst occurring over 3 frames, but smoke obscured much detail after that. Several 'flares', possibly burning pieces of explosive being ejected from the cylinders, were seen through the smoke following the event.

At the slow heating rate, reaction occurred after 1622 seconds (27:02 minutes). The measured temperature was 221°C, corresponding to an explosive surface temperature of 219°C. The baseplate was bulged 9 mm; the top plate had the plug blown out and was bulged 7 mm. The outer cylinder was split into several pieces, as was the aluminium liner. Both inner cylinders were severely bulged and the lower one was split into 2 pieces. Traces of explosive residue, present as a thin film, were found on the end plates. This reaction is classed as an explosion.

4. DISCUSSION

4.1 SSCB Test Responses

The response given by the explosive material in the SSCB test can be assessed by the condition of the various parts of the SSCB; in particular, the degree of bulging of the endplates and/or the presence of a hole in the baseplate, and the degree of fragmentation of the cylinders are important indicators. The only available literature on SSCB testing [35] lists reaction severity of several types - detonation, violent explosion, deflagration, burning - together with descriptions of the damage observed, but does not attempt any systematic categorization of the responses; in this respect, the SSCB test is less well documented than the SCB test, where a rating scale from R-0 to R-10, ranging from burning through to detonation, is available [36].

As a result of the tests reported here and elsewhere [40], a scale of test responses has been established as follows:

Response	**Observed Damage to SSCB**
Mild burning	Little or no damage - SSCB intact
Burning	Outer cylinder split Inner cylinders undamaged
Deflagration	Outer cylinder split/fragmented Inner cylinders distorted
Explosion	Outer cylinder and liner fragmented Inner cylinders split/fragmented Severe bulging of endplates
Detonation	Considerable fragmentation Baseplate holed

This scale lists the main points on which an assessment of the type of reaction should be based. It does not attempt to include actual measurements of plate bulging or number of fragments produced in the response classification, since these parameters show a continuous, and often overlapping, gradation over the range of responses. The bulges found in the end plates from the tests described above are tabulated, for the different responses, in Table 4; the scatter and overlap can be readily appreciated. The presence of unconsumed explosive residue should also not be taken to indicate mild response; such residues have been found following explosions and detonations (see Tables 2 and 3). It must be appreciated that there is no sharp boundary between the various types of response, and it may be convenient on occasion to describe responses of a given type as 'mild' or 'violent', within the categories described; however, the scale above provides a convenient and useful categorisation.

It should be emphasised that the SSCB test is not intended to provide an unequivocal definition of a particular energetic material's cookoff response, but merely an indication of the type of reaction which can be expected. Indeed, the results presented in Table 3 for RDX/TATB/Viton 35/60/5 show that a single composition may give widely varying responses; several other materials tested gave similar but not identical responses in duplicate tests. Widely varying responses can also be observed when materials are tested in full munitions tests; eg. PBXN-103, when tested to WR-50 (now DOD-STD-2105 [1]) requirements, gave fast cookoff responses ranging from burning to explosion, and slow cookoff responses ranging from burning to detonation [41].

It is also important to note that, in assessing the cookoff behaviour of an energetic material, the mere absence of detonative behaviour will not necessarily ensure an appropriately low hazard rating for a munition system. Violent responses (less than detonations) of booster explosives could give sufficient shock stimulus to a main charge for a shock-to-detonation transition to occur [27], or hot, high-velocity metal fragments from a violent explosion in a booster assembly could initiate a main charge [39].

4.2 SSCB Cookoff Behaviour of Meltable Explosives

The reactions observed for the various meltable explosives examined (TNT-based compositions and tetryl) were found to be more violent at the fast heating rate than at the slow heating rate, a phenomenon contrary to that expected, since it is generally accepted that the cookoff response of explosives becomes more violent as the heating rate is reduced. Although the use of sealed-base aluminium liners was reported to prevent loss of molten sample which would lead to a consequent reduction in event severity [38], this was not found for the tests reported here.

The loss of melted sample from the SSCB is not due simply to the volumetric expansion - reduction in density - which accompanies melting. For TNT, for example, the density of the molten material is 1.462 Mg/m^3 at 81°C, and reduces to 1.423 Mg/m^3 at 120°C [41]; the available free space in the SSCB is such that it can accomodate a density reduction to about 1.09 Mg/m^3. The fact that sample will not be lost through volume expansion was verified for tetryl, by heating a loaded SSCB to about 150°C and maintaining it at that temperature for 15 minutes - sufficient to allow the sample to become completely molten, and a comparable time to that observed until reaction at the slow heating rate. After cooling, examination of the SSCB showed no loss of sample.

The video record of an SSCB test of tetryl at the slow heating rate showed that loss of sample occurred over a considerable period prior to the runaway reaction, and that as the temperature increased the molten material was forced from the SSCB at an increasing rate. It is considered likely that this is due to decomposition of the sample, leading to generation of gaseous products within the molten material which force the liquid from the SSCB through the (small) gaps, particularly that around the thermocouple. Although no decomposition products were detected in the residues recovered (at levels estimated to be < 1%), this is not considered to negate this hypothesis. Very little material need decompose to generate a few cm^3 of gaseous products which is sufficient to generate internal pressure to force material from the SSCB, and the material actually exuded need not be that which has decomposed.

The SSCB is not considered to be suitable for testing the cookoff response of materials which melt at temperatures considerably below that at which reaction occurs; sample loss, which is not prevented by using sealed-base aluminium liners, will lead to a reduced response simply due to the reduction in the amount of explosive present. However, at the fast heating rate, reaction will occur before appreciable loss of molten material occurs, and a valid assessment of the cookoff behaviour will be obtained.

The results reported in Table 2 for meltable explosives at the slow heating rate should therefore be treated with scepticism; it is considered unlikely that such responses would be obtained in a real-life situation where confinement of the explosive would exist. The slow heating rate response for Composition B, however, is likely to be valid; the large amount of RDX in this material (which will not be lost from the test assembly) will contribute to the detonation observed.

The result for TNT at the fast heating rate is also considered not to represent a true indication of the real-life response of this material in a full-sized munition. The melting point of TNT is so low (80°C) that, even at the fast heating rate, much of the sample will be molten prior to reaction. The size of the SSCB test assembly is much lower than the critical diameter of both cast (solid) and molten TNT (15.9 mm diameter sample, and critical diameters of 26.9 mm and 31.3 mm respectively [42]); test results which can be scaled to larger sizes will only be obtained when the critical diameter of the explosive is less than the diameter of the sample in the SSCB [35].

4.3 SSCB Cookoff Behaviour of RDX/TATB/Viton Compositions

The reactions observed for the RDX/TATB/Viton compositions were found to be (with one exception) more violent at the slow heating rate than at the fast heating rate, in accordance with the generally accepted belief. Similarly, as the TATB content increased, the violence of the response decreased. The responses observed are similar to those reported by NWC [35]; a detailed comparison, showing both the type of response observed and the explosive surface temperature, is presented in Table 5. The explosive surface temperatures at which reaction occurred were found to be similar for all the compositions, and ranged from 255-274°C at the fast heating rate, and from 210-221°C at the slow heating rate. This contrasts with SSCB results reported by NWC [35], where explosive surface temperatures of 221-264°C were found at the fast heating rate (with no correlation with TATB content), and explosive surface temperatures of 187-246°C were found at the slow heating rate, with a marked increase in the temperature being observed between TATB contents of 60% and 75%. A similar variation of cookoff temperatures with TATB content has also been reported for RDX/TATB/PTFE compositions, using a small-scale fuel fire cookoff test [43]. The lack of any marked variation of cookoff temperature with TATB content observed in this study suggests that, in all the compositions examined, the cookoff reaction is being triggered by the RDX, which is the less thermally stable component of the composition (critical temperatures for RDX and TATB, in small-size Henkin-type tests, are 215-217°C and 331-332°C respectively [7,42]). It should also be noted that the temperatures observed at the slow heating rate correspond closely with the temperatures quoted in many sources for RDX decomposition/explosion, indicating that reaction of the RDX is indeed the trigger for the cookoff event in these compositions, while the TATB serves to moderate the response, leading to less violent responses as the TATB content increases.

4.4 The SSCB Test Assembly

The SSCB test assembly, unlike the SCB test assembly [4,36,37], does not provide a pressure-sealed environment for the material under test. The outer cylinder is not fully sealed to either endplate (although it is a close fit into grooves in both these plates), and the thermocouple entry point through the top plate is also unsealed. The central hole, closed with a pipe plug in the top plate, will be sealed prior to reaction, but this is likely to be the weakest part of the system; for all but the very mildest burning reactions, this plug was blown out. Accordingly, the SSCB test will give no pressure containment once reaction starts, and the response observed may not correlate with that which would be given in a system with appreciable pressure confinement.

The lack of sealing is evident when meltable materials are tested, particularly at the slow heating rate (see section 4.2). The use of a sealed-base aluminium liner does not overcome this problem, and the presence of an additional layer of material between the explosive and the baseplate may affect the 'signature' hole produced in the baseplate when detonation occurs. Some evidence for this was found when RDX/Ethylene-Vinyl Acetate (EVA) compositions were tested [40]; detonations which produced similar fragmentation gave smaller, more ragged, holes on the few occasions when sealed-base liners were used. Since the sealed-base liners offer no improvement to the overall test method, and may be deleterious in assessing response, they will not be used in future SSCB tests.

Although holing of the baseplate is the prime factor for defining detonation response, it should be noted that the endplates may be considered to be equivalent in this test (although the test geometry is not symmetrical). Unlike a gap test, where initiation of a charge from one end proceeds to give a particular response on a witness plate at the other end, initiation of reaction will occur at some random position within the explosive in the SSCB test. The non-uniform bulging and damage observed for the inner cylinders, in particular, shows that initiation may commence at different points for every test; the top plate may well be the 'baseplate' for an event which starts near the base of the SSCB. Such a situation was observed for the RDX/TATB/Viton 70/25/5 composition at the slow heating rate, where the detonation produced a hole in the top plate, while the baseplate was only bulged. It may, therefore, be appropriate to modify the SSCB test vehicle geometry to produce a symmetrical system, and eliminate the plug/hole in the top plate (a proven weak point, see previous paragraph). However, this plug does serve as a valuable safety factor during assembly of the test vehicle [35], and since no test response classifications obtained to date are believed to be in doubt, such a change will not be undertaken.

5. CONCLUSIONS

The Super Small-scale Cookoff Bomb test has been established as a test facility at MRL Melbourne, and can be used to determine the cookoff response of energetic materials using a relatively small sample of about 20 g of explosive. It is well suited to carrying out preliminary evaluations of new energetic materials and formulations.

The SSCB test is not suitable for evaluating the cookoff response of materials which melt at temperatures considerably below that at which reaction occurs, since loss of sample will occur prior to the cookoff event. This is not prevented by using sealed-base liners in the SSCB test assembly, and such liners will not be used in future SSCB tests; the lack of any true confinement in the test assembly means that exudation of molten sample under pressure generated in the test assembly cannot be prevented.

The SSCB responses obtained for a series of RDX/TATB/Viton compositions agree reasonably well with those reported by other workers. The SSCB test, as described by NWC [35] and in this report, should be considered as a standard test for preliminary evaluation of the cookoff response of energetic materials, and results from any laboratories using this test should be comparable.

The cookoff temperatures observed for the RDX/TATB/Viton compositions did not show a variation with TATB content, as reported by other workers. The reason for this is not clear; further work in this area could be valuable in arriving at a clearer understanding of the mechanisms of cookoff reactions.

The scale of responses described in this report (see section 4.1) provides an appropriate method of reporting SSCB results. The type of response obtained for any single SSCB test of a given material should not be taken as an unequivocal definition of that material's cookoff behaviour under the conditions used, but should provide a guide to the expected behaviour. The test should be considered to be a comparative test, by which different materials can be ranked regarding their cookoff behaviour, rather than a definitive test. The conduct of a large number of replicate tests, to obtain a statistically significant definition of cookoff behaviour, is not appropriate for a screening test such as this.

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Table 1 **Explosive Compositions for SSCB Testing**

Composition	Fabrication Method	Density (Mg/m^3)	%TMD
TNT	Melt-cast	1.60	(a)
Composition B (RDX/TNT : 60/40)	Melt-cast	1.69	(a)
Pentolite (PETN/TNT : 50/50)	Melt-cast	1.65	(a)
Tetryl	Pressed	1.55	90
RDX/TATB/Viton			
95/0/5	Pressed	1.63	90
70/25/5	Pressed	1.66	90
35/60/5	Pressed	1.70	90
20/75/5	Pressed	1.66(b)	87
PBXW-7, US Type II	Pressed	1.70	90

(a) TMDs are not given for these compositions, since they will melt during the test, before reaction occurs.

(b) It was intended to test all pressed compositions at 90 %TMD; this material was inadvertently pressed to a lower density.

Table 2 Results of SSCB Tests of Meltable Explosive Compositions

Composition	Heat Rate	Temperature Bomb	Temperature Expl.	Time (sec)	Cookoff Reaction
TNT	Fast	367	343	422	Burning
	Slow	296	295	3156	Mild burning (d)
Composition B	Fast	277	246	255	Detonation (b)
		280	248	245	Violent explosion
	Slow	214	212	1520	Detonation (c, d)
Pentolite 50/50	Fast	265	234	238	Explosion
	Slow	254	252	2432	Mild burning (d)
Tetryl (a)	Fast	285	257	239	Detonation
		268	238	240	Detonation
		268	239	(e)	Detonation
	Slow	207	205	1123	Burning (d)
		198	196	1180	Deflagration (d)
		199	197	1177	Deflagration (d)

(a) Although the tetryl charges were fabricated by pressing, the results for tetryl are included in this table since tetryl melts at a temperature well below its cookoff temperature.

(b) Probable detonation - see text.

(c) Deflagration to detonation transition - see text.

(d) Explosive residue recovered after test.

(e) Incorrect heating rate at start of test.

Note: Temperatures are in °C.

Bomb temperature is that recorded by the thermocouple in the slot in the aluminium liner.

Expl. temperature is the explosive surface temperature obtained from the appropriate calibration curve.

Table 3 Results of SSCB Tests of RDX/TATB/Viton Compositions

Composition	Heat Rate	Temperature Bomb	Temperature Expl.	Time (sec)	Cookoff Reaction
RDX/TATB/Viton 95/0/5	Fast	(a)	260	271	Detonation
	Slow	219	217	1577	Detonation
RDX/TATB/Viton 70/25/5	Fast	294	265	294	Deflagration (b)
	Slow	223	221	1543	Detonation
RDX/TATB/Viton 35/60/5	Fast	290	262	302	Burning (b)
	Fast	297	270	263	Detonation (c)
	Slow	212	210	1462	Explosion (c)
PBXW-7 Type II	Fast	293	265	266	Burning (b)
	Slow	215	213	1657	Deflagration (c)
RDX/TATB/Viton 20/75/5	Fast	(a)	255	250	Burning (b)
	Fast	283	255	248	Mild burning (b)
	Fast	302	274	277	Burning (b)
	Slow	221	219	1622	Explosion (c)

(a) No temperature record obtained - explosive temperature estimated from time to reaction.

(b) Explosive residue recovered after test.

(c) Traces of explosive on metal parts after test.

Note: Temperatures are in °C.

Bomb temperature is that recorded by the thermocouple in the slot in the aluminium liner.

Expl. temperature is the explosive surface temperature obtained from the appropriate calibration curve.

Table 4 End Plate Damage for Different SSCB Responses

SSCB Response	Baseplate Bulge (mm)	Top Plate Bulge (mm)
Mild Burning	3	5
	0	2
	2	5
Burning	8	7
	5	6
	4	4
	4	6
	5	5
	5	6
Deflagration	8	8
	10	9
	7	7
	9	9
Explosion	10	10
	9	11
	10	7
	9	7
Detonation	hole (a)	15
	hole	11
	hole	12
	hole	9
	hole	14
	hole	16
	hole	15
	10	hole
	hole	9

(a) Baseplate supported - see text.

Table 5 **Comparison of SSCB results for RDX/TATB/Viton Compositions Response obtained and explosive surface temperature (°C)**

Composition (a)	Heat Rate	MRL Results Response/Exp. temp.	NWC Results [35] Response/Exp. temp.
RDX/TATB/Viton 95/0/5 (b)	Fast	Detonation / 260	
	Slow	Detonation / 217	Detonation / 219
RDX/TATB/Viton 70/25/5	Fast	Deflagration / 265	Detonation / 264
	Slow	Detonation / 221	Detonation / 187 Detonation / 219
RDX/TATB/Viton 35/60/5 (including (PBXW-7 Type II)	Fast	Burning / 262 Detonation / 270 Burning / 265	Violent Expl / 223
	Slow	Explosion / 210 Deflagration / 213	Violent Expl / 212 Detonation / 219
RDX/TATB/Viton 20/75/5	Fast	Burning / 255 Mild Burning / 255 Burning / 274	Burning / 255
	Slow	Explosion / 219	Deflagration / 250 Deflagration / 246

(a) Compositions used in the NWC work were described as RDX/TATB/Wax, modified PBXW-7; it is assumed that the wax present in these compositions was Viton A, as used here.

(b) Composition tested by NWC was CH-6 (RDX/Wax 96/4).

APPENDIX A

Slurry Coating Method for Preparation of Moulding Powders

The RDX/Viton and RDX/TATB/Viton compositions were prepared according to the following general method. The RDX/Viton was prepared using Grade A RDX, in order to provide samples having the same particle size as a series of RDX/EVA (ethylene-vinyl acetate) compositions also being examined for cookoff behaviour [40]. The RDX/TATB/Viton compositions were prepared using blends of RDX Grade E and TATB Grade B. All the compositions had a nominal explosive:Viton A ratio of 95:5.

A slurry prepared from 95 g of the explosive and 500 ml of distilled water was vigorously agitated for 15 minutes, and 10 ml of a 0.01% aqueous solution of Mowiol 4-88 (a partially saponified polyvinyl alcohol) was then added. 50 g of a 10% w/w solution of Viton A in ethyl acetate was then added, and the mixture was heated and maintained at 60°C for 90 minutes. During this time, hard granules of moulding powder were formed. The mixture was then cooled and the granules were collected by filtration. They were washed thoroughly with water and dried at the pump and then in an oven at 60°C under vacuum and in the presence of silica gel.

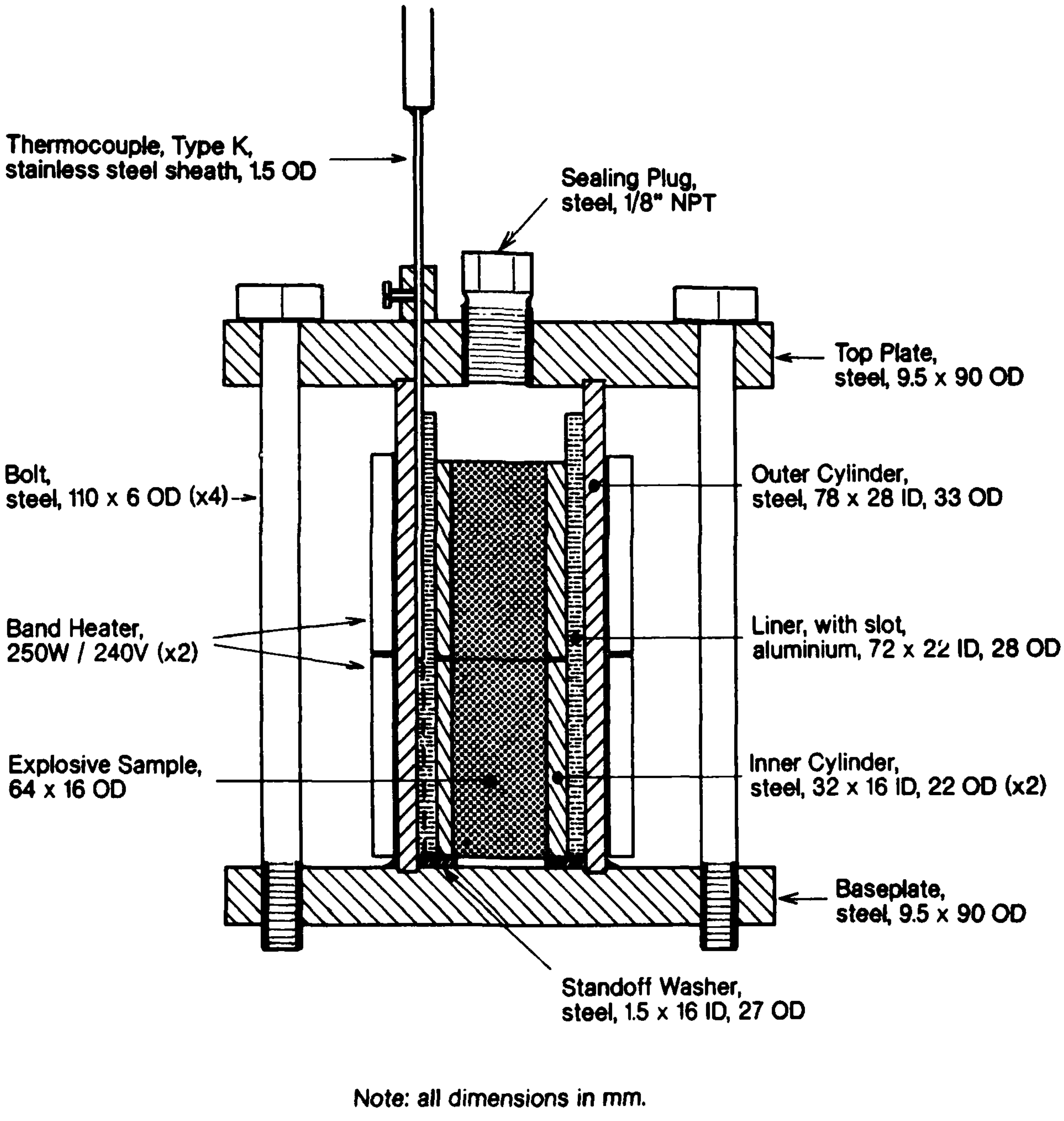

Figure 1 Super Small-scale Cookoff Bomb Test Vehicle Components

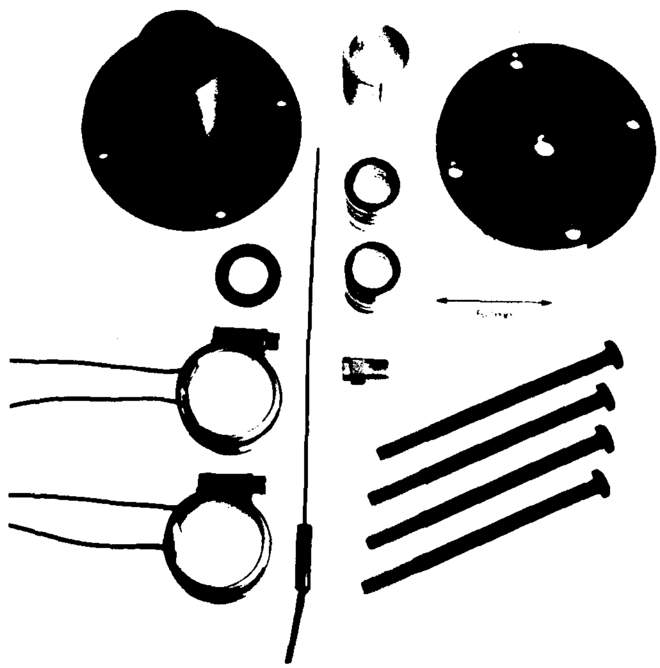

Figure 2   SSCB Test Vehicle Before Assembly

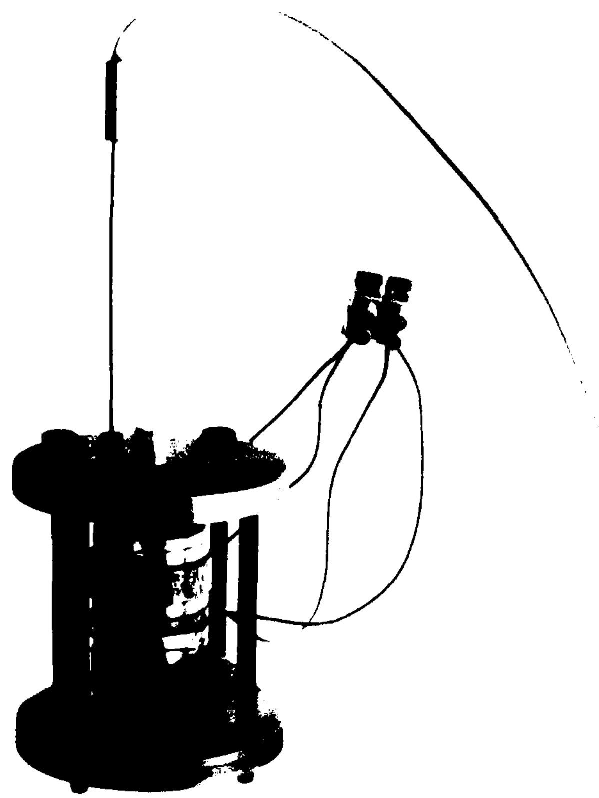

Figure 3 SSCB Test Vehicle after Assembly

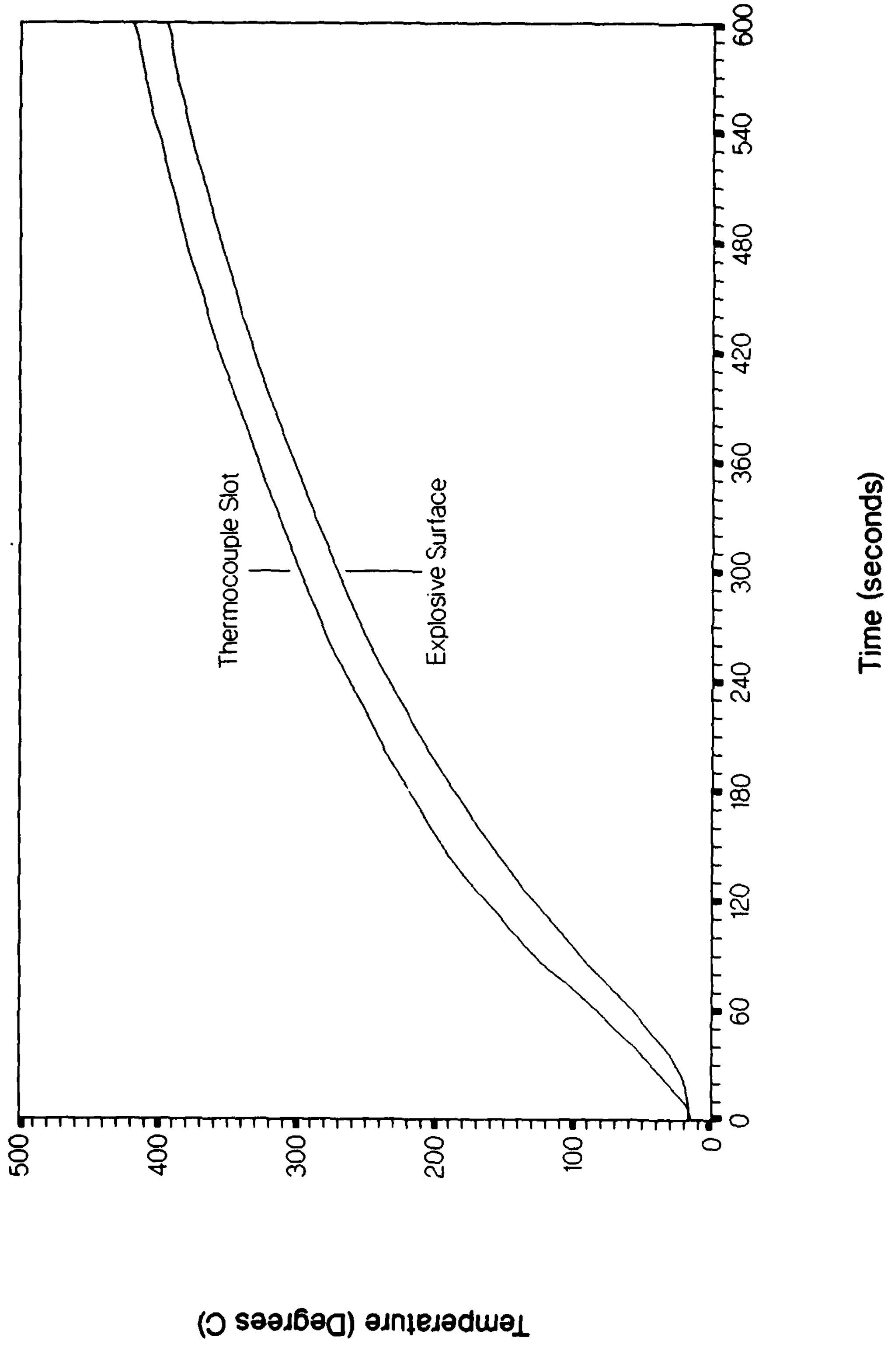

Figure 4 SSCB Temperature Calibration Curves, Fast Heating Rate

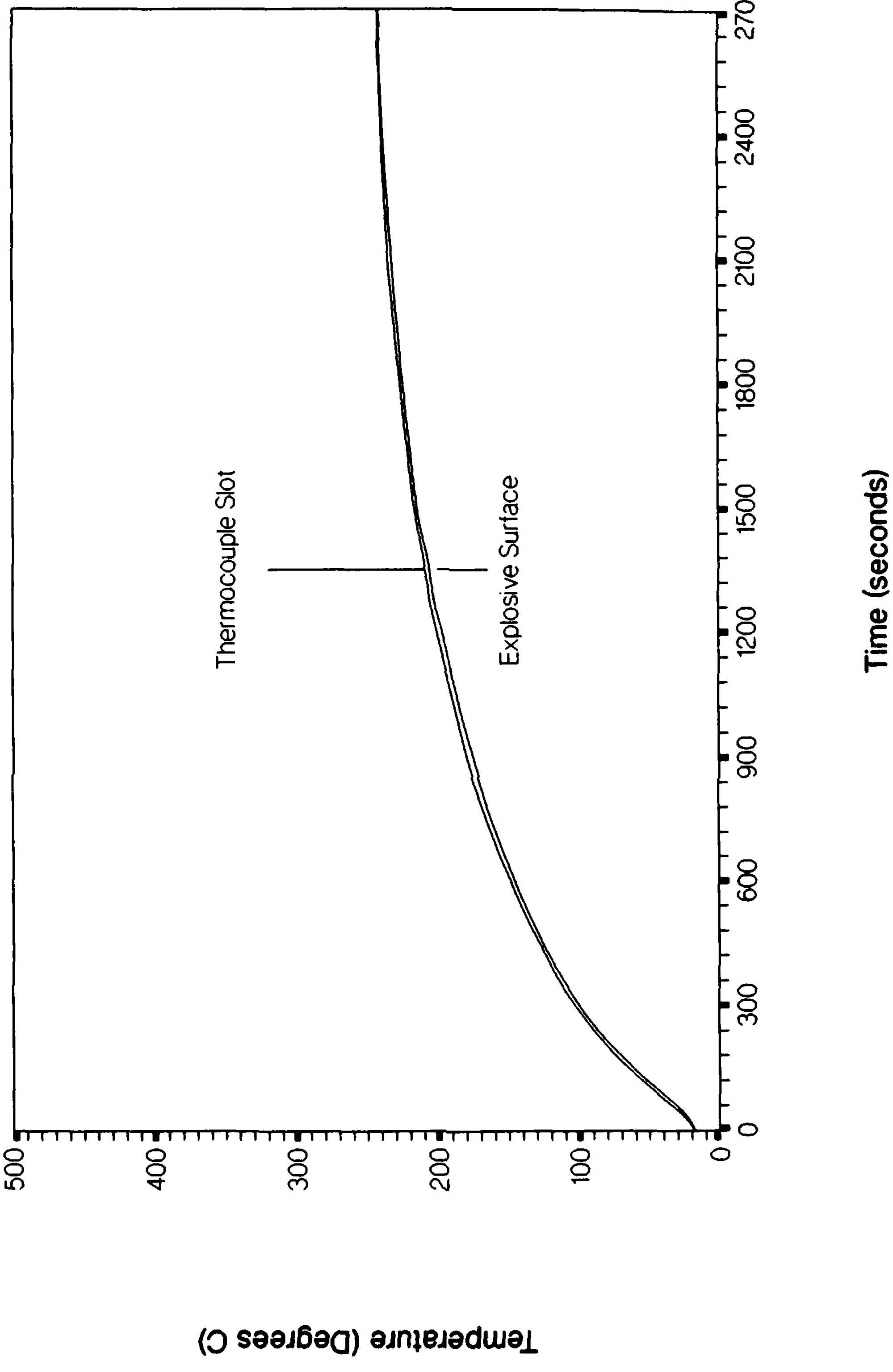

Figure 5 SSCB Temperature Calibration Curves, Slow Heating Rate

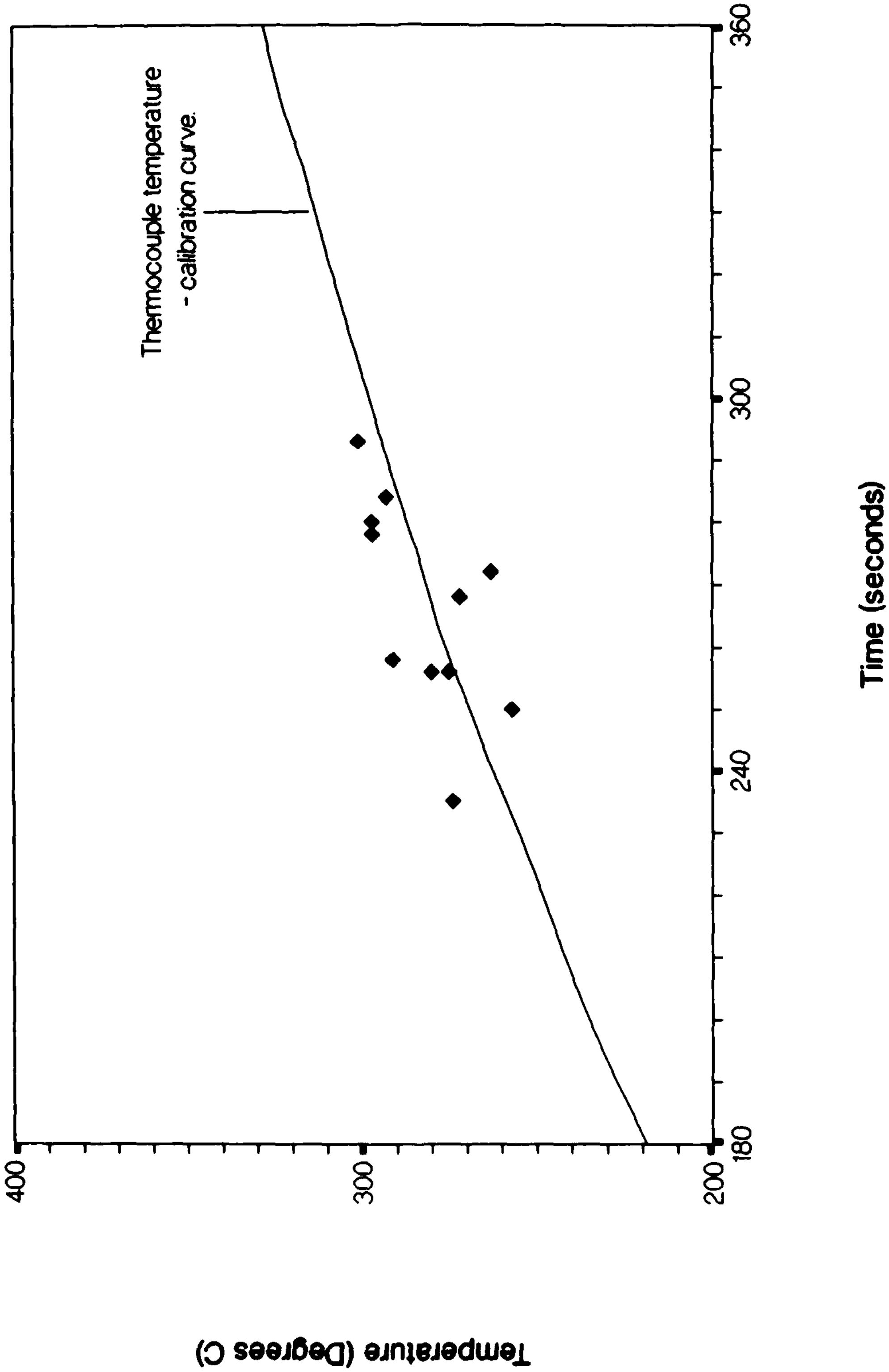

Figure 6   SSCB Temperature-Time Variation, Fast Heating Rate

Figure 7 SSCB Damage, before Disassembly, Mild Burning

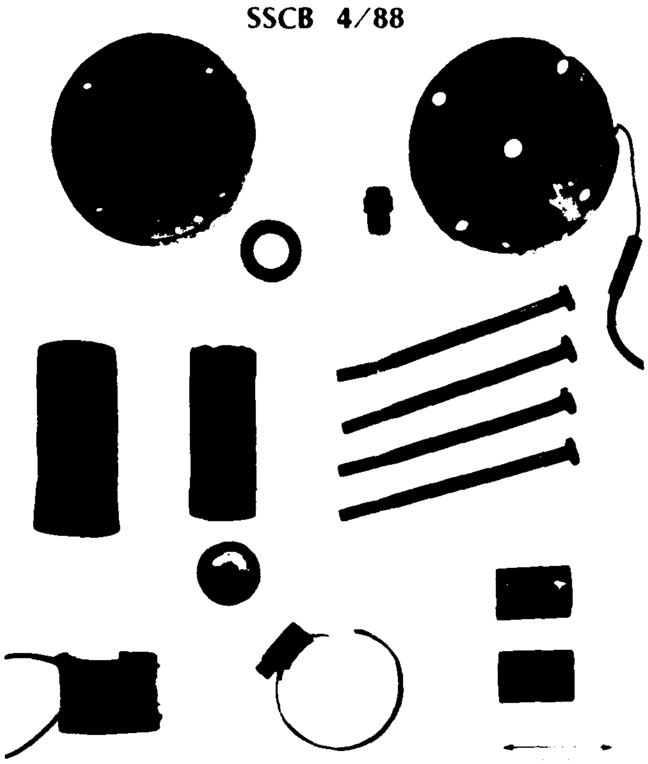

Figure 8 SSCB Baseplate Damage and Fragmentation, Mild Burning

Figure 9 SSCB Baseplate Damage and Fragmentation, Burning

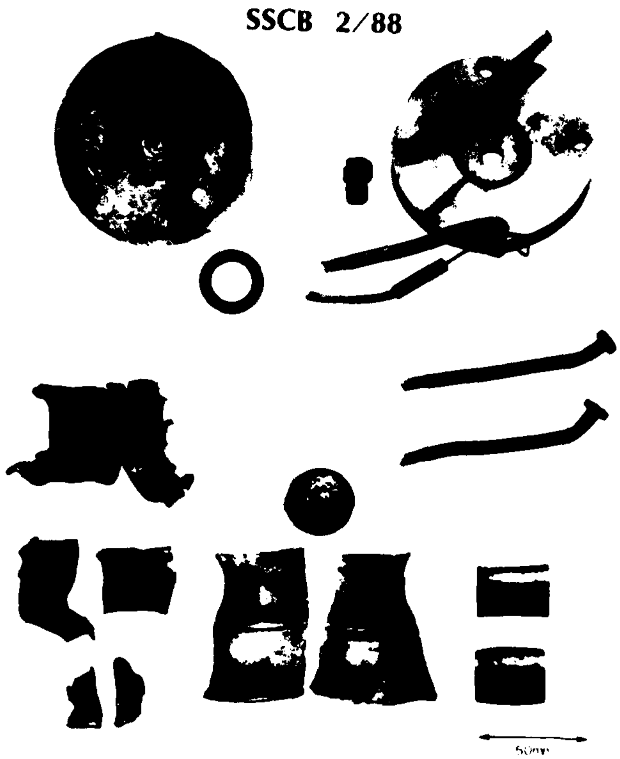

Figure 10 SSCB Baseplate Damage and Fragmentation, Deflagration

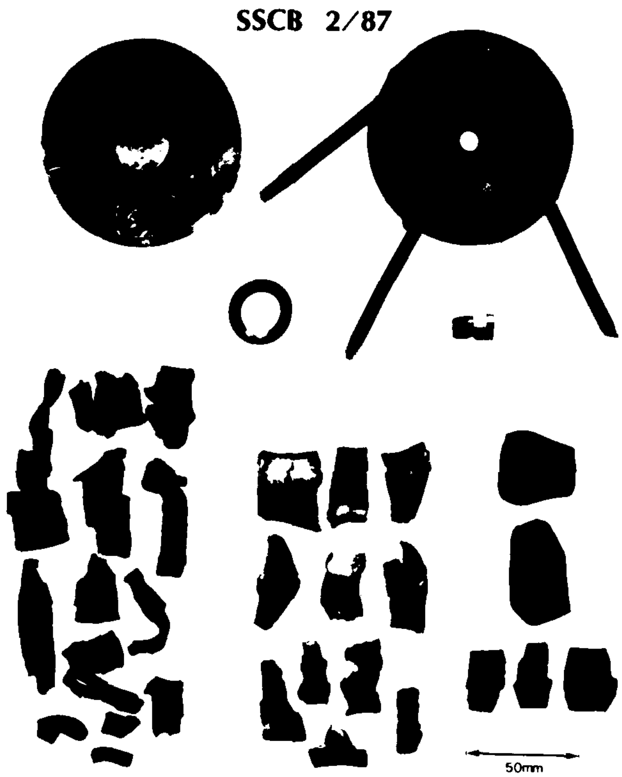

Figure 11 SSCB Baseplate Damage and Fragmentation, Explosion

Figure 12 SSCB Baseplate Damage and Fragmentation, Detonation

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AUTHOR(S)	CORPORATE AUTHOR
R.P. Parker	DSTO Materials Research Laboratory PO Box 50 Ascot Vale Victoria 3032

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ABSTRACT

A Super Small-scale Cookoff Bomb (SSCB) test facility has been established at MRL to provide data on the cookoff behaviour of energetic materials. The test uses an explosive sample of about 20 g, and the heating rate can be varied.

This report describes the test equipment, and reports SSCB test results for several melt-cast explosives and a series of RDX/TATB/Viton compositions.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED